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Quarterly Technical Summary

Division 6

Space Communications

15 March 1977

Prepared for the Department of the Air Force
under Electronic Systems Division Contract F19628-76-C-0002 by

Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LEXINGTON, MASSACHUSETTS

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The work reported in this document was performed at Lincoln Laboratory, a center for research operated by Massachusetts Institute of Technology, with the support of the Department of the Air Force under Contract F19628-76-C-0002.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

Raymond L. Loiselle

Raymond L. Loiselle, Lt. Col., USAF
Chief, ESD Lincoln Laboratory Project Office

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LINCOLN LABORATORY

SPACE COMMUNICATIONS

QUARTERLY TECHNICAL SUMMARY REPORT
TO THE
AIR FORCE SYSTEMS COMMAND

1 DECEMBER 1976 – 28 FEBRUARY 1977

ISSUED 11 MAY 1977

Distribution limited to U.S. Government agencies only; test and evaluation; 9 May 1977. Other requests for this document must be referred to ESD/TML (Lincoln Laboratory), Hanscom AFB, MA 01731.

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INTRODUCTION

This Space Communications – Division 6 Quarterly Technical Summary covers the period 1 December 1976 through 28 February 1977. It includes satellite communications work performed within Divisions 6 and 7. Other work in Division 6 is reported separately.

During the last quarter, a set of performance measurements was made on LES-8/9 command, uplink, and crosslink receivers. The tests included gain, sensitivity, IF-filter passbands of all receivers, and measurement of the automatic signal and phase-lock circuits in the crosslink receiver. The purpose of these tests was to determine the performance status of the receivers and to compare the results with those taken about six months previously. The test results indicate that the performance of the receivers is unchanged, with the exception of some minor variations in the IF-filter responses.

The Lincoln terminals have been engaged primarily in Phase IV (cooperative demonstrations and measurements with the Service terminals) of the post-launch LES-8/9 communications tests. Work directed toward concluding the few remaining Phase III (link-measurements) tests also has continued. The specific roles of the Laboratory's K-band airborne-command-post (ABNCP) and UHF force-element terminals (FET) in conducting tests of the LES-8/9 forward, report-back, and conferencing links are summarized in the following sections.

A problem developed recently with the 5V(3) converter on LES-8, which caused that voltage to drop to zero for extended periods in an unpredictable manner. Consequently, on 8 February 1977, commands were sent to LES-8 to switch the load normally carried by converter 5V(3) to 5V(2). 5V(2) powers much of the Attitude Control System (ACS), and this entire operation required careful coordination and monitoring as power-line glitches would scramble volatile storage in the ACS. The switch-over was accomplished without incident except that the third-generation gyro (TGG) drift-rate compensation was observed to have changed sometime after the switch.

Work has continued on architecture concept development for future MILSATCOM systems and for analytical investigation of spacecraft signal-processing techniques. In separate tasks, support was provided to the ongoing MILSATCOM architecture efforts at both SAMSO/SKX and the MILSATCOM System Office (MSO) of the Defense Communications Agency (DCA). Analytical studies and simulation of on-board signal-processing techniques were instituted that could be useful in next-generation MILSATCOM systems, particularly those operating in the UHF band and serving a large number of small, mobile terminals.

Donald C. MacLellan
Head, Communications Division

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Associate Head

15 March 1977

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REPORTS ON SPACE COMMUNICATIONS

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Technical Notes

TN No.				DDC No.
1976-18	Adaptive Nulling with Multiple-Beam Antennas	J. T. Mayhan	30 September 1976	AD-A034652
1977-8	A Wideband Waveguide Lens	A. R. Dion	2 February 1977	*

Meeting Speech

MS No.			
4317	Adaptive Nulling with Multiple-Beam Antennas	J. T. Mayhan	IEEE Int. Antennas Propag. Symp. Digest, University of Massachusetts, 11-15 October 1976, pp. 471-483

* * * * *

UNPUBLISHED REPORT

Journal Article

JA No.			
4627	Scattering by Multi-Layered Lossy Periodic Strips with Application to Artificial Dielectrics	J. T. Mayhan L. L. Tsai† T-K. Wu†	Accepted by IEEE Trans. Antennas Propag.

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ANTENNAS
GROUP 61

I. INTRODUCTION

Group 61 is concerned with the development of antennas and associated microwave components. Particular emphasis is placed on satellite, ground, and airborne antenna systems.

II. LES-8/9 ANTENNA SYSTEMS

All antenna systems on both LES-8 and -9 and their associated ground terminals located on laboratory buildings continue to function normally. Some additional testing, to reduce several discrepancies between expected and actual link power, is to be conducted at a later date.

III. ADAPTIVE ROUTING

A. Introduction

As part of its satellite communications program, the Laboratory is studying a number of techniques which might permit more effective military satellite communication systems in the future. These studies are being sponsored primarily by the Air Force under the program name "Adaptive Routing."

MILSATCOM systems should be able to discriminate between desired signals and interference (jamming). Modulation techniques which spread the signal bandwidth beyond that required by the data rate are widely used for this purpose. Additional discrimination can be obtained, in principle, by designing a receiving antenna which discriminates adaptively between signal and interference on the basis of direction. We have begun to study the feasibility of such a spacecraft antenna system operating at UHF.

B. Scale-Model Measurements

Evaluation of the scale-model UHF paraboloid/antenna configuration utilizing a 7-element feed network and manually adjusted phase and amplitude weights is nearing completion. This test phase has been successful in several ways. Actual measurements have been found to be in good agreement with theoretical predictions. Test equipment and techniques have proven to be adequate, with some minor modifications, to measure accurately RF characteristics of any candidate antenna system contemplated in the future.

C. Adaptive Nulling

The basic limitations of the conventional Applebaum-Howells nulling algorithm have been discussed in previous Quarterly Technical Summaries. Of these limitations, the basic trade-off between speed of response and the dynamic range of jammers which can be nulled was made evident. The possibility of enhancing the operating dynamic range using second-order loop filtering has been proposed. The basic characteristics of such a system have been studied briefly and found to have the following characteristics: (1) The second-order system tends to equalize the adaption time for the largest and weakest jammers; and (2) a significant increase in dynamic range is possible using a second-order system; for example, assuming $BW \cdot t_a/5 = 30$ dB (BW = nulling bandwidth, t_a = adaption time), approximately a 10-dB increase in

dynamic range is possible. The effects of component errors, channel mismatches, and other nonideal considerations on these results are yet to be examined. A computer program is being written to estimate the effects of these component/fabrication errors on both the first- and second-order systems. Furthermore, the amplitude/phase frequency response of the 7-beam paraboloid are being measured to obtain quantitive data on the amount of channel-channel frequency mismatch.

A simple class of uniformly spaced arrays was studied by evaluating their performance characteristics relative to approximating the behavior of an equivalent filled aperture. The array geometry consisted of 7, 13, and 19 elements arranged in a hexagonal lattice. The viewpoint of illuminating the earth field of view (FOV) with a set of either 7 or 19 beams, the composite of which covers the entire earth FOV, was used to illustrate the trade-offs involved in the choice of array symmetry and element spacing. It was shown that for the 7-element array, keeping the grating lobe out of the FOV dictates a compromise between the minimum beamwidth achievable and the grating lobe position. For the 13-element array, this problem does not arise for diameters $\lesssim$40 ft. However, the symmetry of the array results in an undesirable −8.5-dB sidelobe level. For filled aperture diameters $\lesssim$45 ft, the 19-element array is the best of those considered in its approximation to the behavior of a comparable filled aperture.

Another interesting feature which arises is that, for a thinned array diameter D' and a filled aperture diameter D, D' is less than D for comparable radiation patterns. For example, with D = 30 ft, a 7-element array with D' = 19 ft gives radiation patterns comparable to those of filled apertures 30 ft in diameter. Similarly, a filled aperture with D = 45 ft is comparable to the 19-element array with D' = 40 ft. It should be mentioned that the results of the study are preliminary and we are just considering the benefits which might be obtained by nonuniformly spacing the elements of the thinned array (see Sec. F). We have not investigated the disadvantages of the reduced antenna gain associated with the thinned array.

Measurements of the amplitude/phase response of the manual weighting network to be used for open-loop adaptive radiation pattern measurements has been completed. Results indicate ≈5° phase variation and ≈0.5-dB amplitude variation between channels over the band 1.3 to 1.7 GHz (scaled frequency). Variation over any 40-MHz subband (≈10-MHz bandwidth at UHF) is significantly less – nominally on the order of ±0.25-dB amplitude and ±1° phase. These variations may limit the measurable null depth of the associated antenna to ~30 dB over any 40-MHz subband. The test setup used has the capability of setting the amplitude to within 0.1 dB and phase to within 0.5°, which effectively quantizes the exact weight settings to these values.

Preliminary nulling measurements have been obtained using the weight network described above incorporated with the 7-element feed and UHF-scaled paraboloid. The procedure used is as follows: the pattern response (amplitude/phase) is measured for each isolated beam port as a function of angle over the FOV and recorded on tape. This data base is then used with a particular nulling algorithm and user-jammer scenario to determine the appropriate weight settings. The associated quantized weights are then installed in the weighting network, and the resultant pattern is measured. Preliminary results indicate measured gain reduction in the direction of the interference ranging from −28 to −40 dB, consistent with the amplitude quantization of 0.1 dB. Comparison of the measured pattern with the computed pattern using the data base and quantized weights indicates good agreement. The main source of error results from the time-delay of several days or weeks between measuring the data base and measuring the nulling patterns during which time the antenna test environment can vary. This repeatability

limitation has been discussed in a previous Quarterly Technical Summary and is consistent with the preliminary measured null mentioned above. Evaluation of the antenna system using this technique is continuing, and will be extended to estimating the bandwidth characteristics of the antenna.

Considerable effort during this period was directed toward the design of auxiliary test equipment to evaluate several antenna configurations which would be possible candidates in an adaptive nulling system. In addition, several radiators suitable for a space environment and capable of meeting RF requirements are being designed as possible satellite antenna elements.

D. Jammer Test Range

The jammer test range will be used to measure the performance of a 1/4-scale model of the UHF nulling antenna over a range of jammer/user characteristics which include angular locations extending to 9° off boresight. Since the required spacings between jammer and user sources increase with increasing separation between the nulling antenna and the sources, it is desirable to make this separation as small as feasible. Although the same adapted radiation pattern can be produced for any separation, it is necessary to ascertain that over a frequency band the nulling performance with short separations is not appreciably different from the nulling performance with large separations. In addition, to make the test range as free of adverse reflections as possible, we require source antennas of as high a directivity as is feasible without modifying nulling performance.

The extent to which the nulling performance is modified by short separations and by directive source antennas is presently being investigated in a computer simulation of the jammer test range. Preliminary results indicate that even with separations as small as 100 ft and with source antenna diameters as large as 5 ft, the nulling performance over a 40-MHz band will differ from the far-field nulling performance by an amount much smaller than the expected measurement accuracy. Still shorter distances are feasible provided the nulling antenna is focused on the sources. These results, however, apply to a specific algorithm with a single null in an earth-coverage pattern. Additional cases will be studied before a separation is chosen.

As mentioned above, it is necessary to make the jammer test range as free of interfering reflections as possible. The largest reflections are caused by the ground. Their intensities depend on the ground electrical characteristics, on the source directivities, and on the range geometry. For a smooth ground plane, the ground-reflected rays appear to come from an image of the source antenna. The ratio of the image intensity to the source intensity (image-rejection ratio) was computed for the Antenna Test Range (ATR) geometry, a source-antenna-to-receive-antenna distance of 200 ft and a 5-ft-diameter source antenna at different heights above ground. The latter antenna remained pointed toward the receive antenna at all heights (as opposed to tilting for increased rejection), the ground electrical characteristics were taken as average (dielectric constant = 10, conductivity = 10^{-3} mhos/m), and calculations were made for circular polarization at a frequency of 1549 MHz. Results indicate a relative image strength about −10 dB, with respect to the source antenna, and nearly independent of height. To further increase the image-rejection ratio, metal fences will be introduced in the path of the reflected rays to prevent these rays from reaching the nulling antenna. Calculations show that with only a minimal number of fences the relative image strength can be reduced to −30 dB. An experimental investigation of the reduction of the amplitude of reflected rays by fences is planned for the next quarter.

E. Nulling Algorithm

As part of the DCA DSCS-III antenna evaluation study, a nulling algorithm has been developed. It applies to the proposed 8-GHz 61-beam cluster-fed lens satellite antenna. It calculates the beam weights to either:

(1) Point shaped nulls in a number of specified directions while maintaining essentially uniform coverage over the remaining FOV, or

(2) Point shaped nulls in a number of specified directions while pointing essentially constant-gain beams toward a set of specified users.

These are known as the earth-coverage and area-coverage modes, respectively.

For the earth-coverage calculation, the algorithm works iteratively, starting from an initial set of weights which are individually either zero or unity according to whether the corresponding beam points in a direction close to a specified jammer direction. The iteration is accomplished by changing the weights slightly, one at a time, and retaining at each step the set of weights which give the better pattern fit. After the weights have all been changed once, the sequence is repeated until no new set of weights is found that is any better than the current one. Then the weight-change increment is reduced and the process repeated. One more weight-change increment reduction is made before the weights are accepted.

The measure of the fit, in the earth-coverage mode, is the number of decibels by which the gain at the sample point of poorest fit is within specification. Thus, to determine the goodness of fit for a set of sample points immediately surrounding a jammer, first find the member of the set with maximum gain (in decibels) and then subtract this gain value from the required null depth in decibels. For the set of sample points in the outer ring zones surrounding the jammer, the goodness of fit is the maximum gain in the ring zone minus the required minimum gain in that ring.

An example of the performance of the algorithm is shown in Figs. 1 and 2. Figure 1 shows the figure of merit statistics for the gain calculated from 25 randomly generated locations of two null directions. The coverage zones are 0° to 0.25°, 0.25° to 1.7°, 1.7° to 2.2° and >2.2°. The required gains in the first, third, and fourth of these were <0, >16 and >18 dB. No specification was made for the second zone. The curves give the statistical average of the calculated directive gain over the individual rings.

Figure 2 is an example of the radiation pattern contours for a single two-null scenario.

For the area-coverage calculation, the algorithm worked iteratively from a starting set of weights which again consisted of ones or zeros. The ones were for those beams closest to the specified user directions. The goodness of fit in the area-coverage mode was taken to be the ratio between the gain at the user point of minimum gain and the gain at the null point of maximum gain. Each user direction and each null direction had associated with it a set of seven user, or null, points defining a 0.29° circle surrounding the user or null direction.

F. UHF Nulling-Array Geometry

Investigations have started to determine how many elements, what element gain and pattern, should be placed at what locations in the array aperture to meet a given set of performance requirements; DSCS-III experience has shown what can be expected if the array aperture is filled.

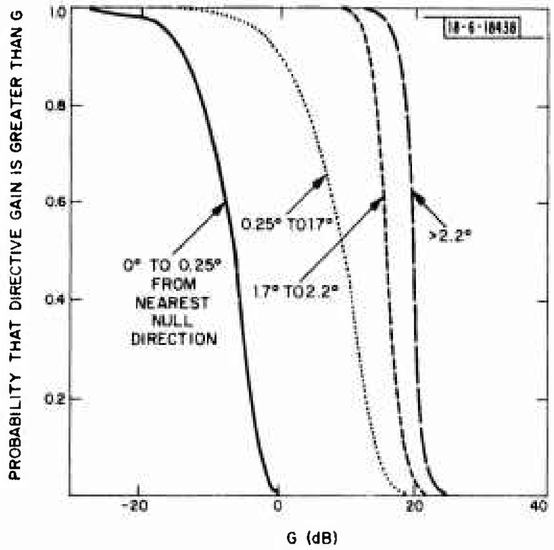

Fig. 1. Figure of merit statistics for two randomly located nulls based on 25 scenarios.

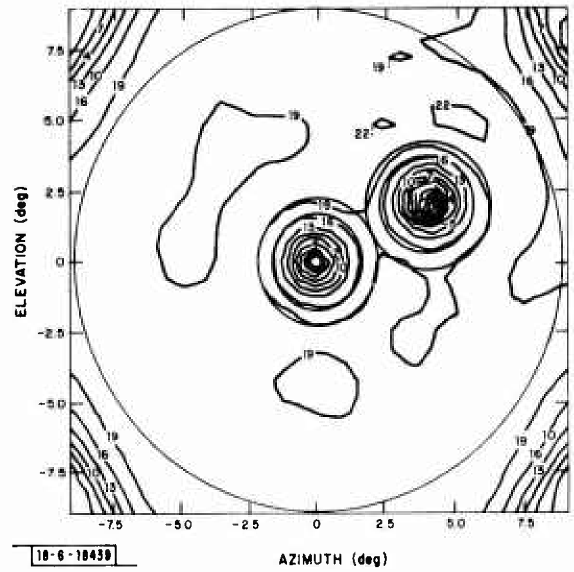

Fig. 2. Pattern contours for two nulls. Circles of radius 0.25°, 1.7°, and 2.2° also are drawn around each null for aid in interpretation.

If this filled array is thinned to the point where grating lobes are just excluded from the FOV, one obtains the conventional regular array of least number of elements necessary to provide the desired angular discrimination and gain. The question now being addressed is to what extent elements can be removed from this array without compromising its performance, and whether it is advantageous to use elements of differing gain and element pattern in the array.

Let us define a regular array as one in which the elements are equally spaced over the antenna aperture (i.e., as on a square or hexagonal lattice). Some early results indicate that the antenna performance obtained with an irrational spacing (i.e., quasi random) between elements has no advantage over that obtained with a regular array having some of its elements missing. Promising results have been obtained when more than 80 percent of the elements of a regular array are removed.

RF TECHNOLOGY
GROUP 63

I. INTRODUCTION

A series of performance tests has confirmed the continued normal operation of the LES-8 and -9 receivers.

A block diagram for the RF and control components of an analog adaptive nulling receiving system has been completed. Progress on the development of UHF transmitters is reported.

II. LES-8/9 POST-LAUNCH PERFORMANCE

A. Receivers

During the last quarter, a set of performance measurements was made on the LES-8/9 command, uplink, and crosslink receivers. The tests included gain, sensitivity, IF-filter passbands of all receivers, and measurement of the automatic signal and phase-lock circuits in the crosslink receiver. The purpose of these tests was to determine the performance status of the receivers and to compare the results with those taken about six months previously. The test results indicated that the performance of the receivers is unchanged, with the exception of some minor variations in the IF-filter responses.

B. VCXO – LES-8

From 2 to 8 February 1977, the LES-8 VCXO was turned off. When it was turned back on, the VCXO oven temperature was monitored as the oven warmed up and periodic plots of AGC voltage vs input voltage were taken for various temperatures from 25° to 77°C. The results of the measurements did not explain why the VCXO has a gain loss for a particular range of input volts (~1 to 4 V). They did suggest, however, that temperature and crystal resonant frequency are not parameters in this complex effect.

C. K-Band Transmitters

The K-band transmitters operated as expected throughout this quarter. The long-term trends of all IMPATT diode voltages and currents are continuing to be monitored via post-processing of telemetry.

III. RECEIVER DEVELOPMENT

A. Adaptive Nulling

In the adaptive nulling area, the idea of characterizing and modifying the Syracuse University Research Corporation (SURC) sidelobe canceller has been dropped. Instead, a two-loop stability analysis has been generated for a first- and second-order adaptive nulling loop which depicts regions of stability for these two cases. The results show that phase and amplitude offsets are more of a problem for the second-order loop but are not unmanageable if the correct operating regions are chosen.

Additionally, a block diagram has been drawn which shows a complete analog nulling loop as is best understood at this time. The diagram includes the RF portion as well as the control section and will serve as a first attempt to define what it is that should be built.

Work has been started on the development of a set of amplitude and phase matched receiver front ends to be used in adaptive antenna nulling systems. Both standard superheterodyne and direct-conversion-to-baseband configurations are under consideration. Preliminary analysis of null depth limitations due to receiver front-end circuits was completed during the last quarter. This analysis examined the effect of component tolerances on the depth of null obtainable as a function of the interfering signal bandwidth. Component tolerances were allowed such that the bandwidths of each receiving channel were allowed to vary ±5 percent, and have up to 0.5-dB ripple. Under these conditions it appears that nulls in excess of 50 dB are obtainable for signal bandwidths less than about 10 percent of the front-end bandwidth. For signal bandwidths greater than the front-end bandwidth, the nulls obtainable are limited to 20 to 25 dB. Work is continuing to define the relationship between component tolerance and null-depth limitations more precisely.

B. Test Source

A new effort is under way to develop circuits and components for a test source for the antenna nulling test bed. A comb generator was built and tested which consisted of a quadriphase modulator driven by a pseudorandom binary sequence (PRBS) generator. Several balanced mixers were evaluated in this circuit. Other components, such as mixers, filters, and amplifiers, frequency synthesizers, etc. were surveyed to be purchased for the system. A block diagram was developed and is now being evaluated.

.V. TRANSMITTER DEVELOPMENT

A. UHF Transmitter

During the last quarter, the design and construction of a 100-W wideband Class C amplifier was completed. The amplifier was constructed with a single 100-W transistor, microstrip inductors, and chip capacitors. The output circuit was measured using the automatic network analyzer and modified to yield the design values without the transistor in the circuit. With the transistor placed in the circuit, only a small amount of tuning was required on the input circuit to produce a flat gain across the band. No tuning was required on the output circuit. The amplifier demonstrated 8-dB gain and a 1-dB bandwidth of 100 MHz at an unsaturated power output of 80 W. Higher output power across the band could not be obtained because of limited drive power available. At a single frequency with 19 W of drive power the output power measured 96 W. Input VSWR was less than 2.6:1 across the band.

More recently, an analysis in the time domain of various output circuit topologies has been done using the IBM 370. Several possible output circuit designs have been analyzed where, with the transistor modeled as a switch in parallel with a capacitor, efficiencies of up to 99 percent are predicted. One of these designs was breadboarded and produced an efficiency of 65 percent at 250 MHz. Work is continuing to determine the cause of this low efficiency.

A slotted-section tuner has been developed for the measurement and characterization of transistors under large signal conditions. In the past this has been a difficult part of the circuit designers' task. Previously, the transistor was matched into a load and then the transistor removed and the characteristics of the matching networks measured. This was a tedious and slow process since one point was obtained for each iteration. The slotted-section tuner allows the transistor output match to be adjusted dynamically while observing the complex load impedance on a network analyzer.

Measurements made thus far with the tuner have been promising. The unit has a broad range: it can tune VSWRs from 1.05:1 to 40:1. Its dissipation loss is less than 0.7 dB for VSWRs up to 10:1. This tuner now gives us the capability to make manual load-pull measurements on available transistors.

A number of transistor holders are being designed to accommodate all the transistor packages under consideration. One holder has been built which allows a transistor to be placed in the circuit without soldering. In this way, transistors may be characterized more quickly, and the holder can be reused.

B. K-Band Transmitters

IMPATT diodes with a low-high-low doping profile have provided 20 GHz amplifier performance of 0.78 W added power at 9.6-percent efficiency. Subharmonic impedance control was provided by including discrete components within the diode package.

Two additional wafers with further profile modifications have been evaluated at K-band. Efforts are continuing to achieve more efficient diode design. In addition, extensive measurements and analysis are being directed toward obtaining wideband, stable amplifier performance through appropriate diode package designs with internal subharmonic terminations.

V. FREQUENCY SOURCES

Two commercially available X-band voltage-controlled oscillators have been received, as has test equipment, including a frequency stability analyzer. Characterization of these sources is beginning.

VI. DEVICE SURVEY

Current capabilities of solid-state power devices (IMPATTs, bipolar, and field-effect transistors) have been reviewed with regard to use in space communication systems hardware. The study is being prepared for publication.

SURVSAT SYSTEMS
GROUP 64

I. INTRODUCTION

Group 64 is responsible for the continuing planning and execution of LES-8/9 experiments and the transferring of associated technologies to potential operational systems. During the quarter, the major tasks of Group 64 involved the following areas:

(a) Planning, executing, and reporting on LES-8/9 communications experiments,

(b) Monitoring and controlling these spacecraft,

(c) Determining and maintaining accurate LES-8/9 orbit-fits,

(d) Developing a candidate Strategic Satellite System (SSS) spacecraft and system configuration, and

(e) Transferring the LES-8/9 technology to potential operational systems of interest to ESD and SAMSO (AFSATCOM) and to the Navy (submarine report-back).

In addition to the efforts which are summarized above, the Group has provided support through:

(a) Commenting on a draft of the final report of the work of the SAMSO-sponsored Survivability Analysis Group (SAG),

(b) Reviewing for the Air Force some spacecraft radioisotope-thermoelectric-generator (RTG) and bipropellant-propulsion-fuel technologies that may be applicable to SSS satellites,

(c) Serving on an Air Force team which reviewed the production readiness of the dual-capability UHF modem developed by the Linkabit Corporation,

(d) Reviewing spacecraft and terminal specifications for the single-channel-transponder (SCT) packages which are proposed for the DSCS-III satellites,

(e) Hosting a meeting to plan the implementation of the DoD's intended interim operational capability (IOC) use of the wideband (500 kHz) transponder modes of LES-8/9, and

(f) Assisting the Aerospace Corporation's efforts to build a UHF radio capable of receiving the LES-8/9 downlink signal.

II. LES-8/9 COMMUNICATIONS-LINK TESTING

During this quarter, the Lincoln terminals have been engaged primarily in Phase IV (cooperative demonstrations and measurements with the Service terminals) of the post-launch LES-8/9 communications tests. Work directed toward concluding the few remaining Phase III (link-measurements) tests also has continued. The specific roles of the Laboratory's K-band ABNCP and UHF FETs in conducting tests of the LES-8/9 forward, report-back, and

conferencing links are summarized in the following sections. Activities associated with the Lincoln K-band Navy terminal are reported separately.

A. K-Band Airborne-Command-Post Terminal

The major activities with the Lincoln ABNCP terminal have been in four areas: supporting an AFAL and ESD demonstration of some of the LES-8/9 communications capabilities to representatives of CINCPAC and others, satellite tracking for recording data for orbit-fitting and for checking the accuracy of orbital predictions, testing the Lincoln Laboratory-built report-back processor, and performing several maintenance and operational-improvement items.

A significant event in the communications test program this quarter was the highly successful Hawaiian flight test conducted by AFAL C-135 aircraft No. 12662 during the period 7 through 15 December 1976. In contrast with previous flights where Lincoln participation was of a supportive nature, this test involved a major role for the Lincoln ABNCP terminal. All links – forward, report-back, and conferencing – were demonstrated during the course of the flight. KY-585/U vocoded voice at 2400 bps and CVSD-digitized voice at 19.2 kbps, both encrypted by KG-34 keystream generators, were successfully demonstrated via the conferencing link. These demonstrations were witnessed by about 50 persons from CINCPAC, PACAF, DCA, and other communications groups, including Brig. Gen. Williams of CINCPAC and seven members of his staff.

During the return flight from Hawaii, the Lincoln ABNCP terminal (located in Lexington) conducted forward, narrowband (single-access) report-back, and wideband (multiple-access) report-back communication with the UHF FETs on board the AFAL aircraft, including the Lincoln-built FET. Alternating periods of forward and report-back transmission were conducted using LES-8. Also, narrowband report-back and simultaneous forward transmission were conducted via the K-band crosslinks between LES-8 and -9.

Report-back-processor modifications to add a 3-channel multiple-access capability and to correct a few design and construction deficiencies have been completed. Operational tests and link measurements to characterize the processor's performance are now being conducted. Some typical results of coded bit-error rate vs uplink-receiver power-to-noise-spectral-density-ratio measurements for LES-9 (in orbit) and the prototype satellite (ground-based) are shown in Fig. 3. These curves are for a frequency-hopped UHF uplink with the satellites in their multiple-access configuration (i.e., wideband sampled channel, 100 kbps K-band downlink). The in-orbit results and those achieved with computer simulations generally agree within the ±2-dB measurement-calibration accuracy. Also, the single-channel configuration (narrowband sampled channel, 10 kbps downlink) consistently exhibits approximately a 1-dB advantage over the data shown. Similar tests with LES-8 will be conducted during the next quarter.

In addition to the above tests, the Lincoln K-band ABNCP terminal supported communications tests conducted by ESD/MITRE, NRL, Aerospace, NELC, and Linkabit, as well as routine Lincoln Experimental Satellite Operations Center (LESOC) RF-system tests and satellite-housekeeping operations. Also, improvements were made in the circuitry used to obtain ranging, coherent-Doppler, azimuth, and elevation-angle tracking data from the K-band ABNCP terminal for the purpose of making orbit-fits.

B. UHF Force-Element Terminal

The acquisition algorithm for the UHF FET has now been refined and tested over its designed time and frequency-uncertainty ranges of ±1 sec and ±1200 Hz using the prototype

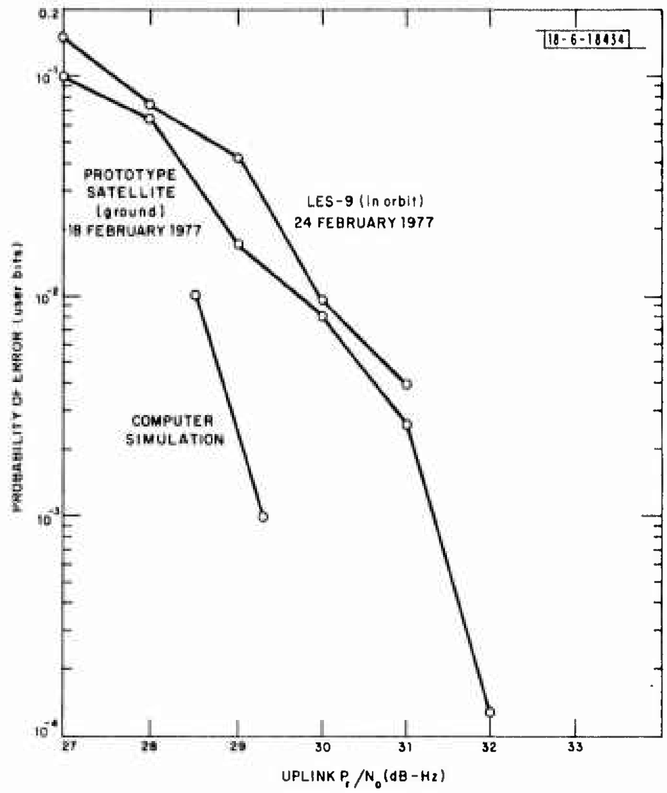

Fig. 3. UHF report-back uplink performance (bandspread, wideband sampled channel).

satellite and FET No. 2. Figure 4 shows the results of this testing (i.e., the time to acquire downlink signals having given fixed time and frequency offsets). Each measured point is an average of 10 acquisitions spread over each 200-msec time-uncertainty slot. Note that even with the UHF downlink signal only 2 dB above threshold, the time to acquire is the minimum in all cases, with worst-case acquisition (−1 sec and −1200 Hz) taking just under 5 min.

Between 7 and 15 December 1976, the Lincoln FET No. 3 successfully demonstrated its airborne operability aboard the AFAL C-135 aircraft No. 12662 flying out of Wright Patterson AFB, Ohio. The aircraft itinerary included a flight to Hickam AFB, Hawaii; two flights while in Hawaii, including one flight back into a region from which both LES-8 and -9 were visible; and a return flight to Wright Patterson AFB. On the first flight, the acquisition capability, the receipt of forward messages from LES-8 (and LES-9) and the transmission of narrowband (single-access) report-back messages through LES-8 were verified. A handover attempt failed because the LES-8 UHF downlink was inadvertently turned OFF from Lexington just at the time of the handover. While in Hawaii, the FET participated in forward and narrowband report-back tests via the crosslinks as well as in wideband (multiple-access) report-back tests through LES-8. On the flight from Hickam back into the dual-satellite coverage, another handover was attempted. Unfortunately, this time the FET suffered a 30-sec time glitch (after operator correction, the terminal reacquired the LES-8 downlink within 15 sec). However, on the return flight from Hickam to Wright Patterson AFB, a successful series of "forced" handovers was conducted by appropriately changing the UHF downlink modes on the two satellites. Dual-satellite communication was also demonstrated using the crosslinks. Forward messages

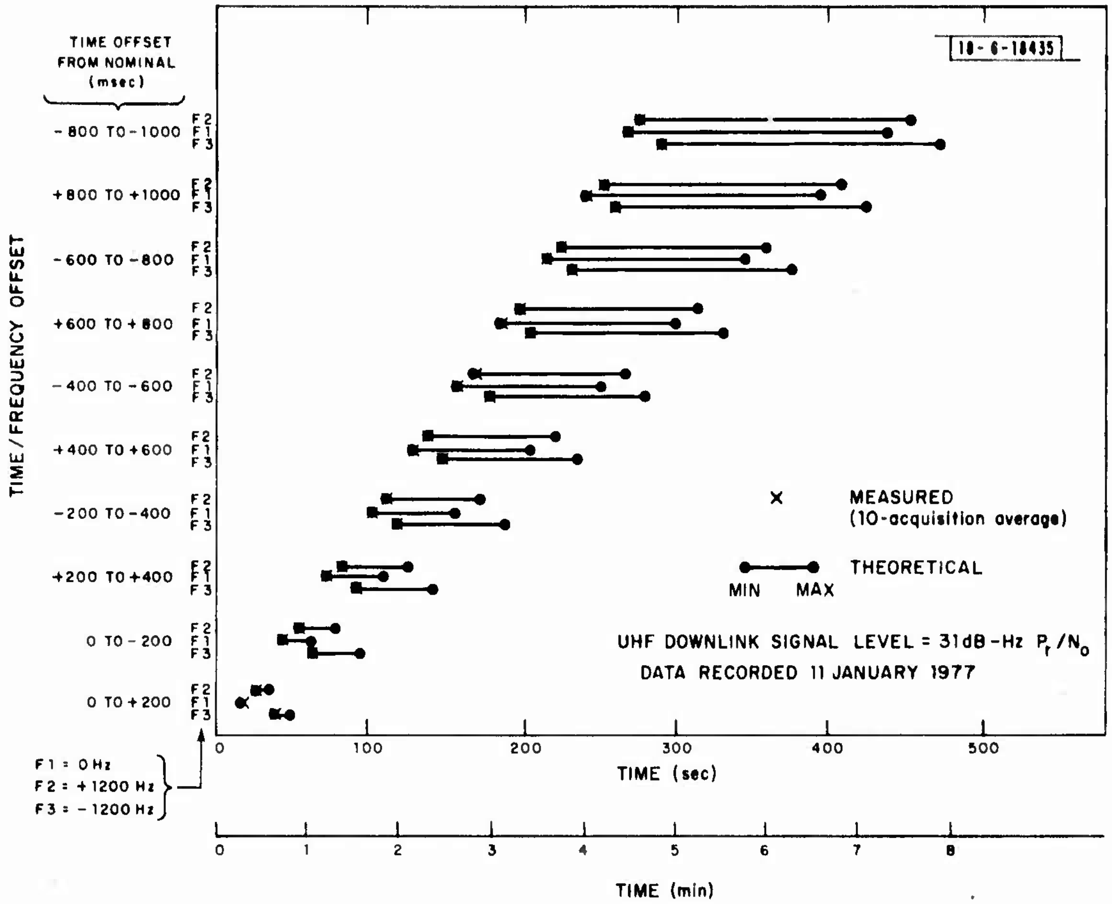

Fig. 4. Acquisition time vs time/frequency offset.

originating in the Lincoln ABNCP terminal went via LES-9 and then LES-8 to the Lincoln FET. Report-back messages from the FET went via LES-8 and then LES-9 to the ABNCP terminal.

III. LESOC OPERATIONS AND HARDWARE

The responsibility for LESOC rests with Group 64, though many people from other Groups participate in its activities. The LES-8/9 communications testing involving Lincoln Laboratory terminals was discussed in Sec. II. Much LESOC effort is devoted to support of tests for the benefit of non-Lincoln terminals and experiments.

In addition to communications testing, LESOC has had ongoing activities in connection with many other LES-8/9-associated enterprises, including:

(a) Evaluation of the TGG on LES-8 by the Charles S. Draper Laboratory (CSDL),

(b) Evaluation of the RTGs on both satellites by GE and ERDA,

(c) Test of the LES-8 stationkeeping system, for which autonomous thrust control ended 4 October 1976, and preparations for test of the LES-9 stationkeeping system,

(d) Maintenance and dissemination to all users of up-to-date orbital data on both satellites, and

(e) Special monitoring of known problem areas on the satellites, specifically the LES-8 VCXO, the LES-9 K-horn transmitter, and the LES-8 +5V(3) power-converter.

Autonomous control of thrusting by the LES-9 stationkeeping system has been deferred until a very good orbit-fit on this satellite becomes available. Several equipment problems within the Lincoln Laboratory K-band ABNCP terminal have had to be fixed. These problems have been responsible for occasional difficulty in making precise LES-8 orbit-fits in the past.

The failure of the LES-8 +5V(3) power converter is described in detail in the Group 68 section of this report. This problem monopolized much of Group 64's resources for the two-week period when LES-8 was declared unavailable for communications testing. Switching the +5V(3) bus from power-converter No. 3 to power-converter No. 2 restored all on-board systems to full operation. Key telemetry points associated with this part of the LES-8 power system are now being monitored automatically, in case the new operating configuration should show any non-standard behavior.

Planning is now under way within the DoD for the time when the formal LES-8/9 Test Program will be over (early in CY 1978) and the satellites become available essentially full time as residual communications assets. In that era, the hour-to-hour scheduling of LES-8/9 users will be shifted from ESD's Test Management Facility (TMF) at Bedford, Massachusetts, to AFCS's Tactical Relay Operations Center (TROC) at Brandywine, Maryland. The responsibility for LES-8/9 command and telemetry functions and all housekeeping-system actions will remain with Lincoln Laboratory and will be exercised through LESOC. The official nickname for this utilization of LES-8/9 is SCOPE DAWN.

Work is under way to simplify some of the LESOC operating arrangements and to provide flexibility and necessary spare parts. The long-term operational mission of LESOC in support of the SCOPE DAWN program requires such provisions.

IV. LES-5/6 ACTIVITIES

LES-5 was not monitored during this quarterly period. We continue to maintain LES-6 as backup for the Atlantic Gapfiller satellite. These two satellites have identical UHF broadband-transponder frequency characteristics, although the EIRP and effective receiving cross-section of LES-6 are significantly less than for the Gapfillers.

On 13 January 1977, a correction of the LES-6 spin-axis orientation was made using the automatic gas-system orientation logic through the 3 p.m.-subsatellite-time fix in the combined-sensor mode. A net change of about 7° was made in the orientation of the spin axis, consuming about 8.5 g of ammonia. The tilt of about 5.5° from the orbit-plane normal before correction was larger than before previous reorientations because no correction was made in the Summer of 1976 (the preceding correction was on 25 March 1976). It may not be necessary to correct the spin-axis orientation more than once a year, but the tilt angle will be checked at least twice a year just in case.

COMMUNICATIONS SYSTEMS
GROUP 67

Group 67 has responsibility for architecture concept development for future MILSATCOM systems and for analytical investigation of spacecraft signal-processing techniques. In separate tasks, the Group is providing support to the ongoing MILSATCOM architecture efforts at both SAMSO/SKX and the MSO of the DCA. The Group is also involved in analytic studies and simulation of on-board signal-processing techniques that could be useful in next-generation MILSATCOM systems, particularly those operating in the UHF band and serving a large number of small, mobile terminals.

SATELLITE ARCHITECTURE STUDIES

In a memorandum dated 17 January 1977, Deputy Secretary of Defense Clements called for a General-Purpose Satellite Communications System (GPSCS) to provide service to mobile ground, shipboard, and airborne users, designated Nuclear Capable Forces (NCF), and the National Command Authority (NCA) in the post-FLTSAT time frame. The MSO was charged with architectural responsibility for GPSCS, while the Air Force (in conjunction with the Army and the Navy) has responsibility for design, development, and procurement of the space segment and management of the overall system (space and ground). In support of initial efforts to define GPSCS, Lincoln has been studying functions required in the GPSCS and has participated in initial meetings with the Services and with the MSO to define the course of action leading to a GPSCS Defense System Acquisition Review Council (DSARC) in Fall 1977.

These meetings, together with previous work by Lincoln, has led us to propose the functional block diagram shown in Fig. 5. The heart of this system is an on-board signal processor which demodulates approximately 100 uplink users (primarily UHF, but also SHF) who access the system by frequency-division multiple access (FDMA). The demodulated data bits would be repackaged into one or more time-division multiplex (TDM) data streams for transmission on the downlinks. Antijam (AJ) protection would be by use of frequency hopping on the uplink at both SHF and UHF. In addition, to raise the protection to a very high level at UHF, further jammer suppression would be provided by an array of UHF antennas with outputs combined so as to put nulls in the composite antenna pattern in the direction of jammers.

To address the problems of backward compatibility and service to the NCF, a number of other functions must also be included. In particular, the large number of SSR-1 FLTBDCST receivers installed by the Navy suggests that a separate downlink in the SSR-1 format must be provided. The uplink for FLTBDCST (at SHF) currently employs pseudonoise spreading; whether this should be retained or a frequency-hopped uplink should be used is open to further study, however. Likewise, the plans for an SCT on DSCS-III and deployment of dual-capability (AFSAT I/AFSAT II) modems in Air Force force elements may require that a similar function must be carried on GPSCS, by means of a special format uplink and downlink. So that these same force elements may make use of the dual-capability modems on transmit, a report-back channel similar to the LES-8/9 sampling channel could be employed. The relatively high rate ($\approx$100 kbps) output of this receiver could be put on an SHF downlink and received by major SHF earth terminals even with the limited SHF EIRP available in the satellite. In addition, it may be possible to reprogram the dual-capability modems to demodulate a modest data rate ($\approx$1200 bps) TDM

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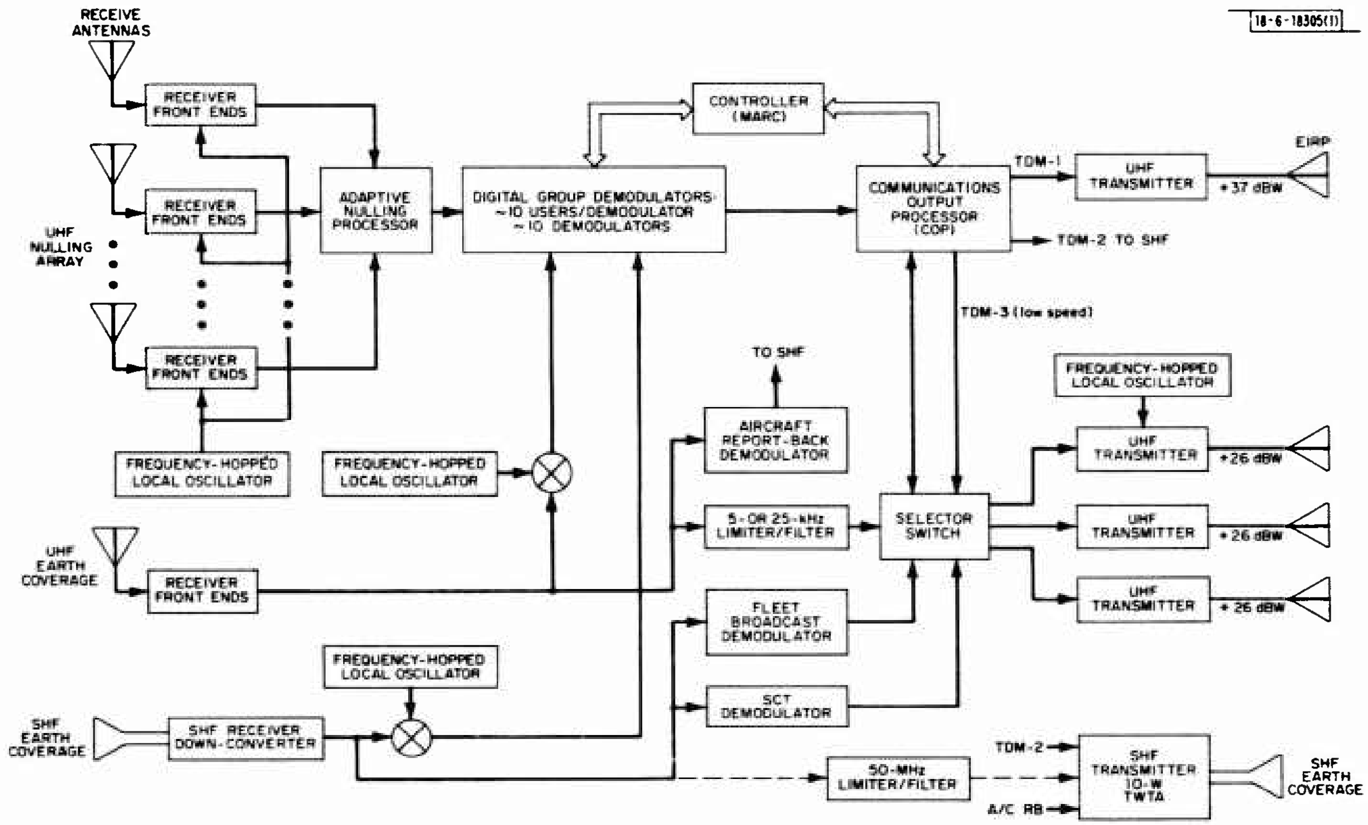

Fig. 5. GPSCS conceptual block diagram.

downlink to provide force direction capability and service to other high-priority Air Force platforms. For further backward compatibility it would be desirable to provide one or more conventional hard-limiting transponders of 5- or 25-kHz bandwidth as in FLTSAT.

The functions described above could lead to a requirement for simultaneous transmission of at least 3 and probably 4 or more UHF downlink carriers. This number should be minimized to keep intermodulation product problems from becoming intolerable. The block diagram shows four power amplifiers, one of 37-dBW EIRP for the main TDM downlink (scaled to meet the 1985 requirements in the MSO Data Base), and three more at 26-dBW EIRP which could be switched among the various uplinks as needed. Typically, one would provide the FLTBDCST downlink and the other two could be used for analog (hard-limiting) transponders. (One of these could provide the low-rate TDM downlink to AF platforms once the dual-capability modems have been acquired and modified for this mode.)

We will be working with the Air Force and the MSO on further studies of this and other candidate spacecraft in the months ahead.

SPACECRAFT TECHNOLOGY
GROUP 68

I. INTRODUCTION

During the past quarter, Group 68 has divided its time between supporting LES-8/9 operations and developing technology for a possible GPSCS. In the ACS area, a yaw axis gyrocompassing system design is being analyzed. In the Power Systems area, a study of flywheel energy storage has led to a unique magnetic bearing design. In the Device Physics area, an Automated Radiation Test Facility capable of testing LSI microprocessor chips is in assembly. A satellite design study was undertaken to investigate the impact on overall satellite configurations of the new communications technologies being developed in Division 6 and to study the applicability of a "Universal Bus" satellite design concept.

II. COMMAND TELEMETRY

A. LES-6 Support

Telemetry data were recorded and analyzed to determine the spin-axis orientation of LES-6 on 12 and 18 January 1977. A thrusting operation was performed on 13 January to change the orientation by approximately seven degrees. An afternoon firing time was used with normal thrusting behavior, giving additional support to the suspicion that the previous anomalies were related only to the morning firing time.

B. LES-8/9 Support

The programming for the slow-code converter breadboard was completed and successful operation of nine simultaneous slow-code outputs with periods from 1 sec to 1 hr was demonstrated. Discussion with ground station personnel indicated that the development of a tenth slow code with a period of 12 hr would increase the usefulness of the converter for current ground-station strip-chart recording activities. Packaging of the converter will be required before it may be used in the ground station.

C. 16-Bit Analog/Digital Converter

The A/D converter design is ready to be converted to printed circuit board construction.

D. Automated Testing System

During the past quarter, a stand-alone automated test facility was defined and a small computer system to control it was specified. The proposed test facility is oriented toward testing analog and digital systems of moderate size and complexity, such as will be under development in the command/telemetry area over the next few years. The immediate use is for the 16-bit A/D converter currently under development.

The specified computer system consists of:

(1) 16-bit CPU, with hardware multiply and divide,

(2) 24K words of semiconductor memory,

(3) CRT with graphics display capability,

(4) Hard-copy facility to reproduce the CRT display,

(5) Dual floppy disk, storing 256K words,

(6) Real-time programmable clock/timer,

(7) I/O facilities to support the above and interface the device under test (two 16-bit parallel ports) to the IBM-370 (one RS-232C port) and the test instruments (one IEEE-488 instrument bus port),

(8) System software.

Emphasis is on the use of FORTRAN to program test routines. A link to the 370 provides the capability of reducing large blocks of data with flexibility in formatting and display. A specification for the computer portion of the system, including a terminal and bulk storage has been completed and requests for information have been sent out.

The IEEE-488 instrument bus is to be used for control of test instruments. For those instruments not available with bus compatibility, custom, laboratory-built interfaces will be used. Custom hardware interfaces are reduced to two designs – a listen box and a listen/talk box. A logic block diagram for the former is complete. The packaging design is also complete and a prototype package has been built. Use of the standard IEEE instrument bus in the proposed system simplifies both hardware interconnection of the instruments and software structure for controlling them.

Investigation of suitable instruments for the test system is proceeding and purchase requisitions are being prepared. The instrumentation includes:

(1) Voltage standard and precision divider,

(2) DVM,

(3) Scanner,

(4) Environmental chamber,

(5) Clock,

(6) Thermometer,

(7) Power supplies,

(8) Function generator,

(9) Digital data generator.

Presently, work is being done on the logic implementation of a microprocessor (COSMAC) based controller for an Interface Technology Model RS-432 microprocessor controlled data and timing generator.

E. Microprocessor Committee

Links Subgroup recommendations have been written and included in the report of the Microprocessor Committee. The approach recommended for interfacing between microprocessor development facilities and the Laboratory IBM-370 computer is use of the Virtual Machine Terminal connection. A box interposed between the terminal and the 370 capable of routing information to and from one or more side ports is proposed. An RCA COSMAC evaluation kit has been configured with RS-232C ports as a base for conducting some experiments with this approach.

III. CONTROL SYSTEMS

A. LES-8/9 Support

A technical memorandum was published describing in detail the attitude perturbations of LES-8 during the NMM malfunction on 16 November 1976.

As a direct result of this operational error, a seminar on the LES-8/9 ACS was given to the Group 64 operating team.

A problem developed recently with the 5V(3) converter on LES-8, which caused that voltage to drop to zero for extended periods in an unpredictable manner (see Sec. IV-A). Consequently, on 8 February 1977 commands were sent to LES-8 to switch the load normally carried by converter 5V(3) to 5V(2). 5V(2) powers much of the ACS, and this entire operation required careful coordination and monitoring as powerline glitches would scramble volatile storage in the ACS. The switch-over was accomplished without incident except that the TGG drift rate compensation was observed to have changed sometime after the switch.

Presently, an investigation of TGG drift rate change is in progress. Prior to the switching, a drift rate compensation had been performed on 17 January 1977, and the drift nulled out. After the converter switch, the drift began to increase substantially in the positive direction. The pitch error was returned to zero by ground command and the compensation of 17 January 1977 was recommended. After 3 days, the pitch error had again become substantially positive. A new compensation was computed and sent, which nulled the TGG drift rate. The question is, why did the drift rate change after the converter switch? The answer appears to be that telemetry was switched from TOC B to TOC A before the switch in order to relieve the load on 5V(2) as much as possible. The TOC supplies 100-kHz timing to the TGG. The logic transient caused a power transient which changed the magnetic bias of the TGG and, hence, its drift compensation. A full report is in preparation.

Several procedures were prepared in support of LES-8/9 operations including:

(1) IRS mirror offsetting commands for specific times and dates to prevent sun or moon entering the IRS field of view,

(2) A procedure for nulling the TGG drift rate,

(3) A procedure for the ACS system during switching of 5V(3) loads to converter 5V(2),

(4) A procedure for attitude reacquisition after (3).

Other tasks in support of LES-8/9 were an analysis of disturbance torques on LES-8 and an investigation of the momentum wheel power on LES-9. The disturbance torques are computed from wheel speed, gimbal angle, and cross-link elevation data. The results are very close to preflight predictions.

B. Attitude Control Systems Studies

The disturbance torque for a candidate GPSCS satellite with long antenna booms has been estimated at about 15×10^{-6} ft-lb peak. This level of torque can be handled by a single, body-fixed momentum wheel system. However, in view of the configuration uncertainty and the fact that the torque estimate depends on symmetry, it is felt that a zero-momentum system with four reaction wheels offers the greatest freedom of growth.

A proposed approach to three-axis attitude sensing is to employ six single-axis rate integrating gyros arranged as a HEXAD. Gyro updating will be by IR pitch and roll earth sensors connected in a gyrocompassing mode. Gyros used in this manner have many advantages, including radiation hardness and immunity to "optical" attack. However, gyro reliability is a question which remains to be seriously addressed. A backup system would be provided which will bypass the gyros and derive yaw error by on-board processing of the sun elevation angle and by using this derived angle together with the earth sensors as direct inputs to the control system. With a small residual pitch momentum, the satellite can coast through the noon and midnight periods in each orbit when the sun is eclipsed or positioned so that yaw cannot be derived. A computer simulation study of this type of three-axis control system will begin shortly.

A breadboard unit has been designed and built that takes sun azimuth and elevation from the LES-8/9 SAZ sensor and electronics, and inputs it to an 8080 microprocessor, for computation of yaw error. Verification of the equations was satisfactorily completed within experimental error. A work statement is being prepared for using the Adcole Corporation sun-sensor test facilities for a more precise verification of the governing equations. Assuming satisfactory completion of this test, the sensors will be interfaced to the 8080 processor for a more complete test that will verify the software.

C. Attitude Sensor Studies

Investigation of star sensors for possible use in a satellite ACS was completed. The conclusion is that there is at the moment no proven star sensor available for long-life satellites ($\geqslant 5$ yr). Investigation of available, reliable gyros is continuing. The best candidates at this time are the Northrop K7G and the CSDL TGG.

A search was conducted for appropriate sun sensors for measuring satellite yaw angle and also for initial acquisition. Adcole and Bedix seem to be the prime candidates at this time.

IV. POWER

A. LES-8/9 Support

Group 68 continues to support in-orbit RTG measurements. A relatively simple blackbox model of the RTGs has been constructed to predict future power output based on post-launch data. This model predicts slightly lower long-term capability than the prelaunch predictions. The model will be updated as data accumulates.

During the last days of January 1977, the LES-8 +5V(3) DC-DC converter developed an intermittent problem. For three periods of 3- to 12-hr duration, the converter output voltage and current fell to zero, disabling the K-band system, biax pointing control system, and associated telemetry. Recovery was ragged with voltage overshoot and large power demand spikes (typically 70 W in amplitude) on the RTG power bus. No command is provided to disable or disconnect this converter from the RTG bus. The K-systems and K-pointing controls were turned off to unload the converter as much as possible. The symptoms persisted with longer intervals between failures. No thermal or usage correlation could be determined.

On 8 February, all loads on the +5V(3) converter were switched over to the backup +5V(2) converter, using a secondary bus relay provided for this purpose. No loss of volatile storage occurred. On 10 February, all K-band functions were restored using the +5V(2) converter.

Attempts to duplicate the failure with a flight backup converter in the laboratory show that many possible failures in the converter control circuits can give the zero-output and turn-on

overshoot. The most likely cause appears to be an intermittent 20-kHz operational amplifier oscillator. No reason has been found for this component to fail, or to expect others like it to fail.

B. Solar Array Orientation System

The effort at Fairchild Industries on the design of a Solar Array Drive Assembly (SADA) was terminated this quarter.

C. Flywheel Energy Storage

During the past quarter, the key elements of a flywheel energy-storage unit for spacecraft applications have been studied. Detailed work on potential technological advances is now under way in several areas.

The flywheel rotor shows two possible solutions giving high energy per unit weight and volume. One, using a 3-D weave to build a subcritical composite wheel of Kevlar and epoxy, is under development at GE. The other, using a bare filament Kevlar concept developed by Johns Hopkins APL (JHAPL), is being analyzed at M.I.T. Lincoln Laboratory to discover its ultimate possibilities. A small test device for specific tests is now being ordered from JHAPL.

The magnetic bearing is the focus of a design effort. It shows promise for application to a high-speed, low-weight momentum storage device. The key item here is to obtain high stiffness without complex feedback electronics for excessive power or weight. An in-house design is now complete; it will be built and tested to determine how well these parameters can be combined. Electronics for this unit are under construction. Also, a numerical analysis of the fields around teeth in such bearings is under way to determine whether a radically different tooth design would provide better bearing performance.

The motor-generator has been specified and a purchase order sent for contracted hardware prototype and design development by a vendor. The touchdown bearings are under study to explore several alternate approaches.

D. Batteries

Work was performed over the last three-month period in the investigation of nickel-hydrogen batteries for a spacecraft application. The NiH_2 cells provide the following significant advantages over NiCd units:

(1) No identifiable wear-out mechanism,

(2) Higher energy density (29 vs 17 Whr/lb),

(3) Insensitivity to overcharge and reverse charge,

(4) Wider temperature operating range ($-5°$ to $+50°C$ vs $0°$ to $+15°C$).

At this time we are writing specifications for our own NiH_2 test system which will be used to obtain hands-on experience with these units.

V. DEVICE PHYSICS

A. Radiation Hardening Technology

Our effort to assess the state-of-the-art of LSI device radiation hardening has continued this quarter with visits to agencies funding research and development in this area. Several key

points are worthy of note:

(1) Key processing parameters for hard-oxide CMOS have been identified by research in several laboratories.

(2) Megarad hardness levels in aluminum gate CMOS of MSI complexity have been demonstrated by several manufacturers.

(3) Hughes Aircraft has demonstrated megarad hardness levels for custom aluminum gate CMOS/SOS devices of LSI complexity as well as for P-surface channel and N-buried channel charge-coupled devices (CCDs).

(4) Problems have been encountered in scaling silicon gate CMOS/SOS to LSI complexity.

(5) Hard CMOS microprocessors and high-density RAMs (1K or greater) do not currently exist, but several development programs are under way funded by DNA (through NRL) and AFAL/AFML.

(6) Some very preliminary measurements of recent I^2L microprocessor technology show promise of hard devices.

B. Radiation Test Facility

Much of the equipment ordered for the calculator-controlled automated radiation test facility arrived this quarter. A great deal of time was spent checking out the equipment and learning to use it under calculator control. Effort during the next quarter will center on integrating the equipment into a functioning test system, including both hardware interfacing and software development.

C. Radiation Exposure Tests

A pair of surface-acoustic-wave (SAW) delay lines, provided by Group 86, were exposed to 5×10^{14} e/cm^2, our standard qualification dose, corresponding approximately to a 5-yr, minimally shielded electron exposure at a geosynchronous orbit [2×10^7 Rad (Si)]. The devices exhibited no measurable change in insertion loss (± 0.2 dB) or in delay time ($\Delta t/t < 1 \times 10^{-4}$), the two parameters of importance for such a device. After only 1 percent of total dose, the YZ-cut lithium niobate ($LiNbO_3$) crystal had darkened noticeably, but apparently this had no effect on electrical performance. These devices may find application in signal-processing problems of the type we expect to encounter in the GPSCS satellite.

VI. SPACECRAFT CONFIGURATION STUDY

Spacecraft configurations applicable to the GPSCS mission have been studied during the past quarter. The following spacecraft characteristics have been identified as desirable:

(a) A UHF receive antenna providing earth coverage to a 2400-bps user with a 100-W transmitter into a hemispherical coverage antenna.

(b) An adaptive UHF nulling antenna array and processor which incorporates at least seven elements to provide at least 30-dB suppression toward unwanted signals.

(c) A signal processor/demodulator which can support one hundred TDMA 2400-bps users and a communications output processor providing a digital bit stream; for the TDM downlink (general purpose users). In addition, the functional equivalent of the SCT channel and the functional equivalent of the Fleet Broadcast channel must be provided by UHF downlinks.

(d) A UHF transmitter/antenna configuration which controls the Intermodulation Products (IMP) and multipactor breakdown problem while providing an earth coverage +37-dBW EIRP TDM downlink and perhaps three +26-dBW EIRP other downlink signals.

(e) X-band equipment to provide some interconnectivity between DSCS and FleetSat users.

(f) Adequate spacecraft Command, Telemetry, Attitude Control, Thermal Control, and DC power to support the above.

(g) A maximum spacecraft target weight of 2300 lb. This would allow launching two satellites from a single shuttle flight using the Boeing Interim Upper Stage (IUS).

SPACECRAFT COMMUNICATIONS PROCESSORS
GROUP 69

I. LES-8/9 ACTIVITIES

A. Stationkeeping System

The autonomous stationkeeping control experiment performed on LES-8 was completed and described in the previous Quarterly Technical Summary. Both LES-8 and -9 stationkeeping systems remain under observation in the passive mode. A stationkeeping experiment to be performed on LES-9, similar to that performed for LES-8, awaits availability of a good orbit-fit.

B. Other Satellite Systems

The master clocks for both satellites were reset to correct for the "leap second" at the end of calendar year 1976.* Operations of LES-8/9 are now covered under Group 64.

C. Telemetry Support

A disk and a computer to interface the disk to the three telemetry computers are installed in LESOC and software which will permit the telemetry computers to use the disk is nearly complete.

II. ADAPTIVE ANTENNA NULLING

A. Introduction

We continue to pursue two separate approaches to the adaptive antenna-nulling problem, an essentially digital scheme which we refer to as "block processing," and an analog feedback scheme. Work on the latter approach is described under Group 61. The work in Group 69 has concentrated on the block-processing scheme. We have begun detailed design of an experimental block-processing system as shown in Fig. 6, which is, essentially, the simpler of the two architectures described in the previous Quarterly Technical Summary. The system is intended to be used to study the performance limitations of a block-processing approach to adaptive antenna nulling, but it is not intended to be a prototype flight system. Therefore, some components will be purchased, and others built, without undue regard for weight or power consumption.

B. Description of the Processor

Referring to Fig. 6, the inputs from N antenna ports are used. After frequency dehopping and separation of the signal at each port into I and Q components in a bandwidth which includes all uplink users, the signals are sampled and digitized. In the system we are building, there are 8 ports and, therefore, 16 A/D converters. The signal bandwidth is 1 MHz. This dictates a 1-MHz A/D sampling rate.

The antenna pattern is formed with weights derived from the uplink signals from a given hop, and the weights are applied to the same data. A delay (buffer) is necessary to compensate for the time taken to compute the weights. We think of the buffer memory contents as time samples of an N component vector (with complex components) and the weight-and-combine operation as the inner product of the signal vector with a weight vector.

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* U.S. Naval Observatory, Washington, DC, Time Service Announcement, Series 14, No. 20 (20 October 1976).

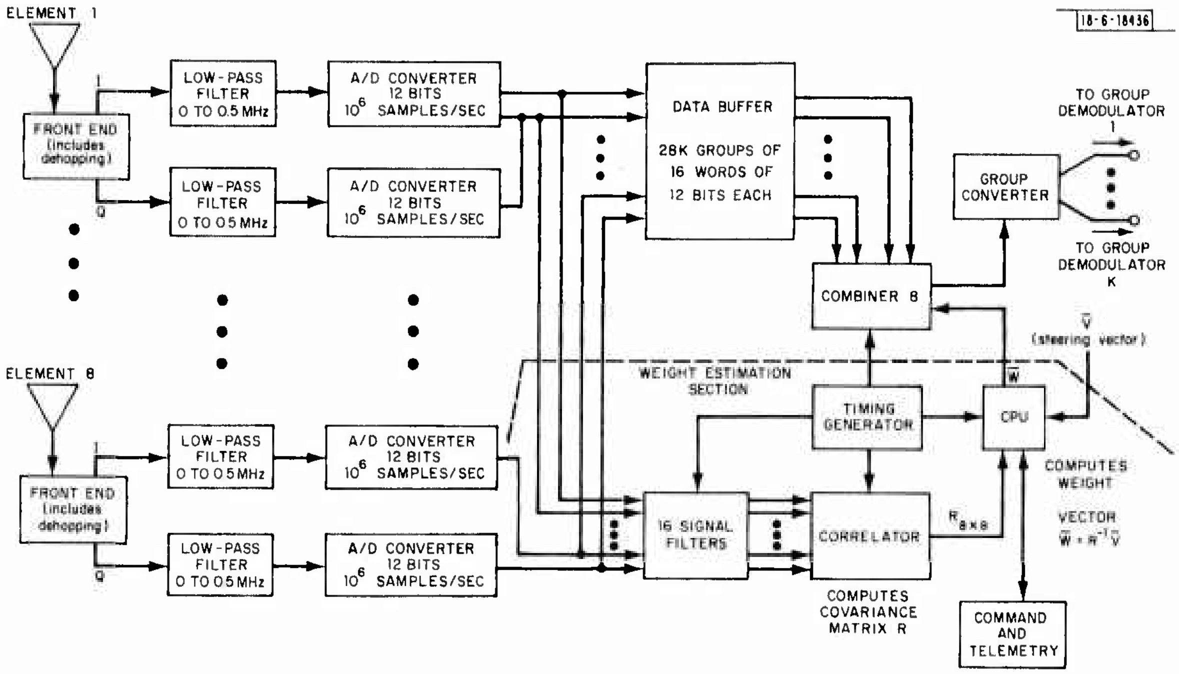

Fig. 6. Concept diagram of block-processing UHF adaptive nulling system.

In the absence of strong (jamming) interference, some weight vector V would be used. We refer to V as a steering vector. V could be chosen to put optimum antenna gain on a user or to favor an area of the earth, or V could be chosen to give earth coverage. To suppress interference, we compute an estimate of R, the correlation matrix for interfering sources, and we use the weight vector $R^{-1}V$. Since the interference correlation matrix must be estimated on the basis of observable signals, there is a danger that it would include a large user component, resulting in suppression of users as well as of interference. Therefore, filtering is necessary to suppress user components in the observables used to form R. This filtering is also shown in Fig. 6, but it is still under study and not yet well specified.

C. Nulling-System General Considerations

1. Processor Development

Detailed estimates of the word-length requirements for a digital nulling processor have been made, such that the processor would not be the limiting factor in achieving a given null depth. The estimates are appropriate to a processor operating with a phased array in which all elements are the same. (The phased array possesses the special property that all element outputs have the same magnitude – and this property has desirable implications for the dynamic range requirements of the processor.) The basic arithmetic function which the processor executes and for which the estimates are derived is the solution of the vector equation RW = V for the weight vector W; R is the correlation matrix for the array outputs and V is the so-called steering vector. The estimates relate the desired null depth to the word length of the processor as shown below for a 7-element system. They should be revised slightly for an 8-element system.

Null Depth (dB)	Word Length (bits)
40	15
50	19
60	22

Floating-point arithmetic has been selected to overcome overflow/underflow problems. These estimates are being tested on the IBM-370 system.

2. System Issues

The relations between adaption techniques/criteria, scenario structure, and array structure are being investigated. Specifically, the following set of questions is being considered:

(a) How does the system performance depend on the jammer-to-user signal power ratio when the system is operated in the "nulling-with-earth-coverage" mode — equivalently, what range of jammer-to-user power ratios is acceptable?

(b) How much improvement in the signal-to-interference ratio can be expected when one switches from the earth-coverage mode of adaption to user optimization and how does this improvement depend on the scenario?

(c) The limitations of the earth-coverage mode, owing to inadequate jammer-to-user power ratios, are most likely to arise with high-rate (2400 bps) users operating in clusters such that they appear as a single strong source. When this situation exists and the users' location is known, area optimization is possible [return to question (b)]. The relevant question is: How dense must a user cluster be for the earth-coverage technique to fail and for area coverage to suffice?

(d) With what accuracy must user locations be known to exploit location information?

(e) How do issues (a), (b), (c), and (d) relate to array structure?

Partial answers to these questions have been found; specifically,

- Under many conditions where an earth-coverage constraint is applied and inadequate user signal-to-interference gain results, exploitation of the knowledge of users' locations can be used to raise the user signal-to-interference ratio to an acceptable level. Calculations show that improvements in the user signal-to-interference ratio typically exceed 9 dB when user-location information is exploited. The precise amount of improvement depends on the detailed structure of the user-jammer scenario and array structure.
- The precision with which user locations must be known for near-optimum processing gain becomes finer as the user signal power increases. A worst-case estimate of location accuracy is ±0.1°,

where the angular location is referenced to the array boresight. The worst-case conditions giving rise to this estimate are: one hundred 30-dBW users closely clustered, operating at 2400 bps; a 10-wavelength, 23-dB gain array was assumed. A location accuracy of ±0.3° would be representative for more typical scenarios.

- It appears that it is not necessary for the array structure to exhibit low sidelobes with the maximum directivity pattern. It is important that the grating lobes of a phased structure be separated at least as far as the angular extent of the earth (viewed from the satellite position). Sidelobes that are down 13 dB or more have little influence on the processing gain of the nulling system.

D. Block-Processing System Components

Work during this quarter covered generation of specifications and evaluation of the various designs for implementing the different sections of the system. Some of the work done for various sections is summarized as follows.

1. A/D Converters

Two converters per antenna element (i.e., one each for I and Q channels) are required. The specifications based on the communication bandwidth and null depths requirement are the following:

Conversion rate	10^6 samples/sec
Aperture uncertainty	20 psec
Resolution	12 bits (including sign)

A market survey indicates that only one vendor manufactures units which meet these specifications. These rack mountable units, however, are expensive and too large in size and power for a feasible satellite system. Development work in this area by other companies is being followed and offers promise. Periodic contact will be made to stay abreast with this work. The specifications for both resolution and aperture uncertainty, especially the latter, are extremely conservative. We have some reason to believe that the specification on aperture uncertainty can be loosened by an order of magnitude, and we are pursuing an analysis on this question.

An alternative approach to A/D conversion for this application combines lower resolution (8 bits) units in a pipelined correction structure to obtain higher resolutions. Parts have been ordered to permit evaluating this scheme. If successful, this scheme should provide 12 bits of resolution with a 2-μsec conversion time and a 10^6 samples/sec throughput rate. Further specifications and test methods are currently being investigated. Equipment for DC testing is currently being assembled and evaluated.

2. Signal Filter

The signal filter is intended to suppress user signals before observables are presented to the correlator. Therefore, the correlator should characterize the interference only. Since user signals will not occupy more than about one-quarter of the 1-MHz band, a filter can be specified to eliminate the user signals while passing some of the interference.

Since interference from an intelligent jammer might be designed to take advantage of the suppression supplied by such filters, their design involves complicated analysis, and interacts with the assignment of users to the available bandwidth. The filter schemes under consideration now are random comb filters and uniform comb filters with random comb spacing. The latter, called accordion filters, are easier to implement and are being examined critically.

3. Correlator

Several multiplication schemes were considered for design of the correlator. A straight one-chip 12×12-bit multiplier design was chosen. A block diagram for this scheme is now ready, and detailed design and parts procurement have begun.

4. Data Buffer

Specifications have been written and information has been requested from vendors on the buffer memory. The buffer memory will be utilized in the system to store data temporarily during the correlation and weight computation cycle, i.e., two hop periods. The memory purchased off-the-shelf will be used for the demonstration system. Survey of low-power memory technology is periodically undertaken with a view toward what would be realistic in a spacecraft. At this time, one vendor is promising a 4K SOS/CMOS memory chip which could be a strong candidate for the data buffer for a flight system.

5. Central Processor Unit (CPU)

The main job of the CPU is to accept the correlation matrix R and to compute the weights using the formula $R^{-1}V$. An algorithm is available which makes use of the fact that the matrix elements above the main diagonal are the complex conjugates of the elements below the diagonal. After the weights are computed, an additional function of the CPU is to compute the contents of the pseudomultiplier memory described below.

For a flight prototype system, the CPU would be a special design. The experimental system, however, calls for a general-purpose processor to permit exploration of word lengths required in each substage of the algorithm (or to permit use of a different algorithm). Approximately 1/75 sec is available for the computations. The arithmetic will be 24-bit mantissa floating point. Neglecting the required square roots and the computational overhead of indexing and data access, we calculate that a Nova Eclipse could complete the computation in 4 msec and a PDP-11-45 in under 2 msec. We are investigating the feasibility of available CPUs further.

In parallel, we are investigating the feasibility of a dedicated CPU as part of a flight prototype nulling system.

6. Combiner

The basic function of the combiner is to compute the dot product of two 8-word vectors, one of which is the weight vector $(W_1, W_2, \ldots, W_8)$ computed by the CPU. The other vector's components are the sampled antenna-port outputs, which have been delayed by the buffer memory. Since each dot product requires eight complex number multiplications, and since a new dot product is required each microsecond, a practical method of implementation, in terms of power consumption, has been sought. We have investigated a number of variations of a scheme we call pseudomultiplication, in which much of the computational effort of the dot product is undertaken in advance and the results stored in a memory (taking advantage of the fact that the weights

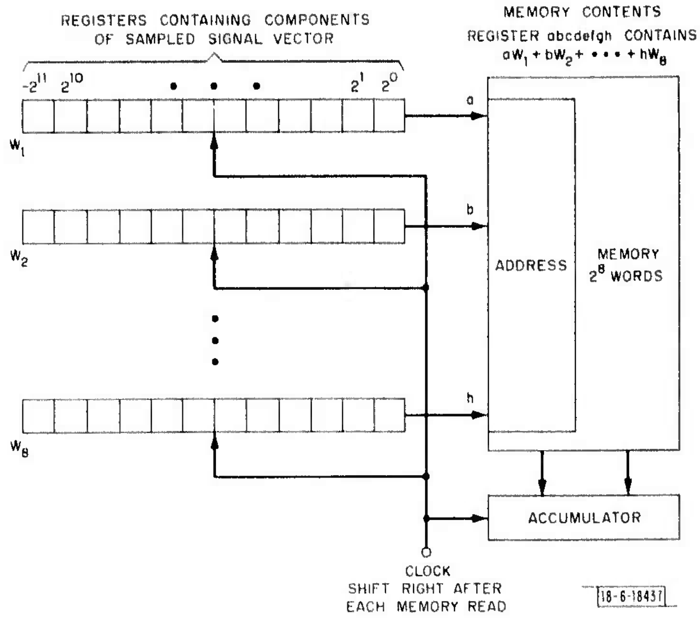

Fig. 7. Simplified pseudomultiplier scheme.

remain constant over a dwell period). As an example of such a scheme, let the memory register whose binary address is abcdefgh (where a to h are bits) contain $F(W) = aW_1 + bW_2 + cW_3 + dW_4 + eW_5 + fW_6 + gW_7 + hW_8$ – sums of some or all of the components of the weight vector. Bits of equivalent value in the binary version of each of the antenna port signals are used to address the memory as in Fig. 7. The results are accumulated with shifting as in a conventional series/parallel multiplier scheme. Figure 7 is simplified in neglecting the treatment of bits in the imaginary components of the antenna port signals.

We are beginning the detailed design of a combiner scheme.

III. ADAPTIVE ANTENNA TEST BED

A. Introduction

"Test bed" means several different things because for the debugging, evaluation, and demonstration of adaptive antenna-nulling systems several very different setups are required. Although the aim of our development is a full-size system to operate at UHF frequencies, there are a number of test situations which call for simpler but different facilities. A processor needs to be evaluated before mating it to an antenna at a range – this calls for a range simulator which simulates the different signals which might be present at each of N antenna ports due to a user or a jammer, for each of several users and jammers. Later, when a processor has been mated to an antenna and is being tested at a range, there is an issue of scale – a UHF system is big and it requires a large antenna range for adequate testing; therefore, we will do most antenna range testing at L-band. Range testing calls for simulated jammers, including both radiating antennas, power amplifiers, and flexible modulation equipment including frequency synthesizers, noise sources, pulse and function generators, comb generators, and distribution networks to permit experiments with "coher-nt jamming." Finally, we can imagine testing a full-scale UHF antenna with a processor at a "big range." Some of the specialized facilities planned are described in the following sections.

B. Jammer Source(s) System*

This system has been designed to allow for growth as the testing requirements of adaptive nulling processors change. The most important components of the system are frequency synthesizers. We require one unit common to all sources and capable of switching (hopping) over the total frequency band of interest at UHF or L-band, and a second unit to provide the local oscillator signal for the system under test, capable of operating over the same frequency range as the first. We also require one or more additional units to drive PRBS generators which in turn drive variable-spacing comb generators.

We expect to provide several jammer source output units (JSOU). One of these would be required for each jammer we desire to simulate. It would be built either at UHF or L-band or, possibly, with relay-switching capability for use at either frequency if it was desirable to reduce the number of units. It would seem prudent to build at least one set dedicated to UHF for use with the UHF range simulator. Other units for range use could be built with dual-band capability for use initially at the ATR and possibly later at a "big range."

Each JSOU would include a programmable level-set attenuator, a pulse modulator, an amplitude modulator, and a VCXO for frequency modulation. Frequency domain modulation (other than FM) would be generated externally – CW, thermal noise, comb, etc. Bandwidth control (selection) would be part of each JSOU. It will be possible to combine frequency modulation with pulse or amplitude modulation using any external frequency domain input. For example, it will be possible to use a comb input that might change its spacing between chips and to frequency modulate the whole comb during the chip interval. The combinations possible are many (to say the least) and should provide sufficient flexibility in generating complex source waveforms.

One wideband noise source will be provided for each JSOU. One noise source will be provided with distribution amplifiers, so that more than one JSOU can be fed from the same source (coherent jammers). We will also provide some number of comb generators (to be determined). Line spacings will be in the range of 5 MHz down to 3.8 Hz. Amplitude flatness on the order of 2 dB for 40-MHz bandwidth is required. Finally, depending on the number of JSOUs and the complexity of the jammer scenarios desired, we will provide pulse generators and function generators.

C. Test Setups

We presently obtain antenna pattern measurements (both phase and amplitude as a function of azimuth, elevation, and frequency) by separately scanning with the antenna under test for each of several measurement frequencies. An alternative method under consideration would require a single azimuth-elevation scan with a wideband (a few megahertz) input. A/D converters would be used to digitize the inputs at the antenna ports and a computer could process these inputs to give the antenna pattern at any frequency. An obvious advantage of the alternative method is that the antenna cannot physically change between measurements at a given frequency (say, due to thermal effects). No steps have been taken to date to provide facilities for such antenna testing.

For testing a processor without an antenna or a range, we need a range simulator and, eventually, a realistic jammer source. The purpose of the range simulator is to allow us to

*See Group 63 section for block diagram and specifications.

test processors in a laboratory environment with controlled repeatable jammer scenarios. Conceptually the range simulator is a simple device. It would take as inputs N jammer sources and give outputs to M antenna ports (inputs to a processor or to beam-forming networks that might precede the processor). It would probably consist of N + M hybrid dividers and summers and N × M adjustable delay and amplitude units. The accuracy required for these latter units, and whether it can be achieved, is under study. It is probable that open-loop control of the elements will not be adequate and that a feedback calibration system under the control of a computer/controller test system will be required.

Performance evaluation would follow preliminary testing. This would require the addition of a PRBS generator and error detector connected with a communications modulator/demodulator. It also would be possible and probably desirable to measure and record the user S/N, as well as bit error rate.

Antenna range testing of a processor mated to an antenna would require the same jammer sources (JSOUs) mentioned above, with the addition of necessary RF power amplifiers. Radiating antennas for the sources will be required, as well as adjustable towers to support the antennas in various positions to simulate different jammer angular scenarios. It is proposed that most jammer source equipment be kept in the antenna test building and the RF be fed out to the source antennas on coax. The final power amplifiers and power monitors would, of course, be located at each antenna.

For full-scale testing at a "big range," the same jammer sources would be used, but different source antennas and power amplifiers would be required due to the change from L-band to UHF.

IV. SATELLITE DEMODULATION/MODULATION

On-board simultaneous demodulation of many UHF uplink users and the formatting of a TDMA downlink in the context of the GPSCS application are being studied jointly by Groups 67 and 69. Many details of the study phase of this work are presented in the Group 67 portion of this Quarterly Technical Summary, to which the reader is referred for orientation.

A. Demodulators

The major effort during this quarter has been to define the satellite signal processor being considered for the GPSCS application. A straw-man design of a multiple-user group demodulator has been worked out, consisting of:

(1) Phase-Comparison Sinusoidal Frequency-Shift Keying (PCSFSK) uplink modulation for AJ, clear, and TDMA modes,

(2) Terminal precorrection of time and frequency, with satellite tracking loops,

(3) Variable bandwidth and data rate demodulators, and

(4) Low-power Schottky-TTL implementation.

The preliminary design estimates have identified areas for further investigation using a complete demodulator simulation. Ideas on bit and phase tracking are just being developed, so most work in this area lies ahead. Regardless of the exact algorithms which will be developed, a paper

design of the demodulator has been attempted which is capable of executing the class of algorithms being considered, as well as the known demodulation requirements of up to 16 users and up to 19,200 bps user data rates.

B. Demodulator Testing

A prototype synthesizer/modulator for testing the above baseline receiver is being developed, featuring programmable center frequency, amplitude, and modulation rate. A test facility would incorporate 16 of these to completely test an uplink group demodulator.

C. Microprogrammed Adaptive Routing Controller

The Microprogrammed Adaptive Routing Controller (MARC) is the system controller for the communications signal processor. It is in the detailed design stage. A feasible instruction set has been chosen. A microprogram assembler for the MARC has been written, which runs on the IBM-370.

A Debugging Interface for the MARC (DIMARC), which permits control and testing of the MARC by a minicomputer, is also in the detailed design phase. A Data General Nova 3 computer has been ordered and will be used in the testing of the MARC. The delivery date is late March.

D. Communications Output Processor

The Communications Output Processor (COP), which controls the flow of data between the demodulators and the TDM downlink and spreads the bits to increase the time per bit if required by low-gain ground terminals, is in the detailed design phase. The COP is being designed to allow the placement of uplink bits in the downlink format in any order. A computer simulation is being performed to determine the relative advantages of different assignment algorithms.

E. Charge-Coupled Devices

The radiation hardness of CCDs was investigated and found to be marginal. In view of the superior radiation hardness of other technologies, e.g., CMOS, CCDs do not seem to be a viable satellite technology.

MECHANICAL ENGINEERING
GROUP 71

I. TECHNOLOGY DEVELOPMENT

A. Introduction and Summary

The satellite technology studies and technique developments are continuing. Various technology deficiencies are being explored. A breadboard design of a boom deployment mechanism is under way.

The test program using eight residual ATS-6 heat pipes has been completed. The tests were to determine the long-term storage effects on aluminum-ammonia heat pipes.

Electronic components, RF packaging techniques, and interconnection systems are being evaluated for the purpose of reporting deficiencies as well as to improve the design and serviceability of RF packages and multilayer boards.

B. Satellite Configuration Studies

Studies are continuing to determine the configuration of a GPSCS satellite which could support the changing communication subsystem requirements.

C. Mechanical Subsystems

1. Solar Array Orientation System (SAOS)

A SADA specification, which was generated by the Fairchild Space and Electronics Company (FSEC), was submitted to industry for the design and fabrication of a breadboard unit. Although a positive response was received from industry, the decision was made in January not to convert the ATS-F' hardware into an experimental satellite. Therefore, procurement activity has been stopped.

2. Deployment Subsystem

A conceptual design of an Orbidrive deployment mechanism for appendages has been completed, and engineering specifications and detail drawings are being prepared for fabrication of a breadboard model.

The mechanism is basically a power hinge utilizing redundant motors, and a system of bearings and Orbidrives which will continue to function with any single point failure. The principal features of this concept are the precise control of deployment rate and the accurate positioning it provides.

3. Separation System

An initial literature research was conducted on a variety of separation systems. One product stands out among all available devices; this product is a reusable low-shock separation unit.

The reusability feature makes an extensive test program possible to increase our level of confidence as to the reliability of the device. The reusable device is available in a variety of sizes to provide a wide range of load capability.

Design of the spacecraft separation subsystem is dependent on such parameters as configurations, weight, etc. Lack of this information suggests that detail study of the separation system should be deferred.

D. Appendage Sizing

A design study of the deployment system of a multielement 40-ft-aperture antenna configuration is in progress. Preliminary analyses are being performed on the sizing of deployable tubular booms utilizing graphite epoxy composite materials. Sample composite materials were purchased for the purpose of verifying published physical properties and developing unpublished data.

Deployment techniques and packaging designs of the deployable elements in the launch configuration are also under study.

E. Materials and Processes

Evaluation of Stored ATS-6 Heat Pipes:– Lincoln Laboratory requested FSEC to review their ATS heat-pipe data and locate certain heat pipes stored at Fairchild with available recorded thermal histories. Lincoln Laboratory selected eight heat pipes for reevaluation using the same acceptance procedure performed $2\frac{1}{2}$ yr ago. Dynatherm Corporation in Maryland manufactured the heat pipes. FSEC contracted with Dynatherm Corporation to perform the reevaluation tests.

The following heat pipes were selected for testing and grouped as shown below:

	Serial No.	Type	Date of Manufacture	Comment
Group I	4E-48	"Cee"	Jan 1972	Undercharged
Group II	5N-39	"Cee"	Oct 1972	Previously accepted
	5N-41	"Cee"	Oct 1972	
	5N-42	"Cee"	Oct 1972	
	5N-44	"Cee"	Oct 1972	
	5N-45	"Cee"	Oct 1972	
Group III	6F02R	Straight	May 1973	
	6F04R	Straight	May 1973	

All pipes were visually inspected, weighed, and NH_3 leak tested using a filter paper and a dilute copper sulfate-ethylene glycol spot test (sensitivity 3.3×10^{-7} SCC sec^{-1}). All pipes passed, and no discrepancies were noted.

The heat pipes were "performance tested" two times at an angular elevation of 0.108° (evaporator above the condenser) with vapor temperatures of 104° and 41°F, respectively. The heat pipes were then operated in a vertical reflux mode at 110°F for 240 hr. Following these initial tests, "footprint" tests were performed on each heat pipe. The "footprint" test consisted of operating the heat pipes with the condenser slightly above the evaporator, with a heat input of 75 W. Three tests were conducted on each heat pipe with vapor temperatures of 104°, 41°, and –40°F, respectively. Temperatures from sensors along the heat pipe "footprint" were recorded when steady-state conditions were established.

The "footprint" test at −40°F is a sensitive test for the detection of gas contamination because of the relatively low vapor pressure of the NH_3 compared to that of the contaminating gas (probably H_2). The contaminating gas will tend to expand and block the condenser, thereby causing a larger ΔT along the heat pipe.

Table I presents a comparison of the average ΔTs between "footprint" data taken in April 1974 and December 1976. Variations of ±1°F are considered within the experimental error of the tests. The 1974 data were taken from the last measurements of a 280-day life test.

TABLE I

COMPARISON OF "FOOTPRINT" DATA FOR ATS HEAT PIPES STORED FOR 2.5 YEARS

Group	End of First Life Test (April 1974) (°F)						End of Second Life Test (December 1976) (°F)					
	104°		41°		−40°		104°		41°		−40°	
	ΔT_c	ΔT_{max}	ΔT_c	ΔT_{max}	ΔT_c	ΔT_{max}	ΔT_c	ΔT_{max}	ΔT_c	ΔT_{max}	ΔT_c	ΔT_{max}
I	4.0	11.8	9.0	19.0	23.5	36.5	4.0	15.0	9.5	22.0	27.5	48.0
II	2.6	11.0	4.7	15.6	7.0	17.7	2.4	10.5	5.5	15.1	11.4	22.5
III	1.7	9.8	1.9	11.8	4.8	16.8	0.8	9.8	1.0	11.8	6.0	17.0

Group I was classified initially as an undercharged NH_3 heat pipe. It has shown further storage degradation by the increased temperature drop (ΔT) during the −40°F "footprint" test. Group II also showed storage degradation as indicated by the measurable temperature differential.

The Group III heat pipes appeared to suffer no storage degradation. The −40°F "footprint" test ΔT was essentially the same after $2\frac{1}{2}$ yr of storage. It should be noted that there was a major processing procedural change for the Group III and subsequent heat pipes because of problems with the earlier heat pipes. That procedural change appears to have been quite effective.

Additional improvements have been incorporated into NH_3-Al heat-pipe fabrication in recent years, particularly with respect to extruded rather than swedged pipes. The extrusion process is inherently cleaner than the swedging process.

The conclusion to the evaluation of stored ATS-6 heat pipes is that good pipes can be stored for several years dormant with no measurable degradation. Flight data indicate that these same type heat pipes can successfully function for an equivalent number of years in the space environment.

F. Electronic and RF Support

1. Constant Impedance Line Adjustment Device

The design of a micrometer adjustment device for use with a constant impedance line stretcher has been released to fabrication. This device will provide a "coarse" and "fine" adjustment capability in the tuning of RF subsystems.

2. Network Analyzer

A rack and panel design is currently under way to house a General Radio Network Analyzer. This design will provide for complete accessibility of units for troubleshooting purposes while under power.

3. Relay Evaluation Test

An evaluation of relays, type 3SAM1702A2, was conducted, focusing on methods for lead termination (solder vs weld). Tests indicated that faulty weld joints exist in these high-reliability components, and that this should be closely observed in any future procurements.

4. Interactive Graphics Design System

A specification to procure a computer-aided graphics design system is now in revision and is scheduled for a March release. This system will enhance the Laboratory's capabilities in logic diagram documentation, producing a wire-wrap tape to drive a semiautomatic wire-wrap machine, and in the design of two-sided and multilayer printed circuit boards.

G. ATS-F' Residual Assets

Fairchild Space and Electronics Company, Hagerstown, Maryland, was revisited in December in an effort to determine which tools and AGE equipment are no longer needed for ongoing satellite programs, and which could be released for disposition through DCAS.

An interim status of transactions was prepared for items of equipment from the inventory which have been transferred to Lincoln Laboratory and for those which have been transferred to NASA/GSFC or loaned for one year to the NASA ISEE-C program. In addition, the equipment which was considered necessary for system testing of a modified ATS-F' satellite was listed, and specific equipment considered useful for ongoing technology was selected for use at Lincoln Laboratory.

However, the decision was made by the Air Force in January 1977 not to convert the ATS-F' hardware into an experimental satellite; therefore, Lincoln Laboratory has no future need of the hardware. The Air Force is currently making plans to dispose of the remaining hardware.

FABRICATION ENGINEERING
GROUP 72

Group 72's efforts in the application and testing of new materials and processes in the spacecraft technology program are continuing in the following areas.

I. HOBBING PROCESS

The development of the hobbing process utilizing the cold-forming technique called backward extrusion to fabricate microwave device cavities and shapes is continuing.

Transducers have been installed to monitor the stroke and pressure of the hobbing press, with the output of the transducers connected to an X-Y plotter. Stroke vs pressure curves have been plotted for various hobbed copper samples, varying the wall thickness and depth of insertion.

Inspection of some rectangular hobbed samples has demonstrated an ability to hold a dimensional tolerance of ±0.001 in. with a finish of 4 to 10 μ-in.

II. ELECTROFORMING

The Udylite Bright Acid Copper Plating Process (UBAC R-1) has been installed.

Six test-sample aluminum mandrels have been plated in the UBAC tank, and six remain to be plated. These plated pieces will be machined, etched clean of aluminum, and tested for their physical properties.

III. EVALUATION OF SPACECRAFT HARDWARE

A. Tensile Tests

The tensile tests on stored spacecraft hardware have been completed, and a test report tabulating the yield load, yield stress, ultimate load, and ultimate stress has been issued.

B. Shear Tests

The double shear strength tests on selected spacecraft hardware have been completed, and a test report including the yield and ultimate loads and stresses has been released.

C. Torque-Tension Tests

The testing program to measure the torque-tension relationship between various combinations of spacecraft hardware is continuing.

The substantial amount of data already compiled indicate a wide range of tensions produced in a bolt under a constant torque, but with varying nut material and lubrication. The results also indicate that, in most cases, a fastener should not be reused after a few insertions due to the large increase of friction.

IV. MULTILAYER BOARDS

Tests are being performed on two different copper-plating tanks used in fabricating multilayer boards, to determine the ductility of the plated copper.

A master tooling bar has been fabricated, which will be used to locate tooling pins in other fixtures to insure layer-to-layer registration.

A punch for punching holes in raw film and circuit board material also is being designed.

A tooling table is being fabricated for the numerically controlled (N/C) drilling machine. Experimentation to find a means of eliminating roughness in small diameter drilled holes is continuing by varying drilling speeds and feeds and also by using three different B-Stage epoxy materials to determine their effect on drilling.

V. GOLD-PLATING FACILITY AND PROCESSES

The contract for fabrication of the facility has been awarded. Fabrication assembly and installation drawings are now being prepared, and will be ready for Laboratory approval within two weeks.

VI. HONEYCOMB FABRICATION TECHNIQUES

The experimental honeycomb fabrication program has yielded flatwise tensile values on sandwich panels fabricated with four different adhesives and two different fabrication techniques (Laminating Press and Vacuum Bag). A test report is being prepared.

VII. NONDESTRUCTIVE EVALUATION TECHNIQUES

Division 7 now owns a Shurtronics Harmonic Bond Tester which operates on the principle of pulsed eddy sonic vibration. This unit is capable of nondestructive inspection of laminations such as honeycomb sandwich panels. To establish test parameters, it is first necessary to set up substrates similar to those to be finally manufactured. Two honeycomb sandwich panels containing known defects have been fabricated and are to be inspected with the Shurtronics Bond Tester.

VIII. ADVANCED COMPOSITE APPLICATIONS

Two types of graphite epoxy material have been procured in order to evaluate and develop our in-house graphite composite technology. Test laminates will be fabricated to test the physical properties. Additional test laminates will then be fabricated with various fiber orientations to develop a zero coefficient of expansion material.

ELECTROMECHANICAL SYSTEMS ENGINEERING
GROUP 73

I. THERMAL ANALYSIS

A. Computer Software

Work continued during this reporting period on improvements to the computer programs for satellite thermal design. The Lincoln Laboratory Transient Thermal Analyzer (LLTTA) is being modified to provide capability for analyzing satellite systems containing louvers for thermal control and to improve the overall capability of the program. Changes have been made to the input preparation portion of the program, and subroutines have been written to handle the bivariate function of power vs time and temperature. Routines will be debugged and the program checked out during the next period.

B. Preliminary Design Analysis

The thermal implications of logic devices planned for use on future satellite systems are being investigated. Power dissipation levels in the order of six times those found in LES-8/9 systems are contemplated. Both packaging and system thermal design aspects will be addressed.

II. STRUCTURAL ANALYSIS

A. Computer Software Evaluation

NASTRAN has been tested and is ready for limited use for static, dynamic, and frequency response analyses. Testing of random response, transient response, nonlinear, and buckling analysis features will be tested if needed during the coming year.

The NASTRAN Thermal Analyzer (using finite elements) has been tested for nonlinear steady-state response and gives comparable results with LLTTA and other in-house finite difference thermal programs. Further testing of the NASTRAN Thermal Analyzer will be carried out for nonlinear transient analysis so that model compatibility may be possible for thermal and structural modeling.

B. Computer Software Development

CMS-ICES development is now complete. A Technical Note* has been published, and a paper will be presented at the 18th ICES Users Group Conference. CMS-NASTRAN and a CMS version of the NASTRAN Thermal Analyzer will be started soon and should be completed within the year.

STRUPLOT, a new ICES subsystem for interactive plotting of STRUDL data and results, is in the final stages of initial development. A paper describing the current features will be presented at the 18th ICES Users Group Conference. Additional capabilities will be added to this system to increase its power and versatility (e.g., more flexible data selection for plotting).

STRUDL has been significantly enhanced during the past year. Most notable improvements have occurred in the finite elements and substructuring capabilities. A Technical Note describing

* B. Schumacker, "Development of a New ICES Executive for the IBM/370 CMS and VS Operating Systems," Technical Note 1977-1, Lincoln Laboratory, M.I.T. (11 January 1977), DDC AD-A037487.

the Laboratory's present finite element dynamic analysis, and substructure analysis capabilities and enhancements should be published in the next quarter.

III. MAGNETIC BEARING INVESTIGATION

A new family of finite elements has been developed within STRUDL for evaluating electromagnetic field problems. This effort has just started, but 2-D and 3-D elements have already been created for the solution of complicated electromagnetic problems in much the same way that complicated structural analysis problems are solved. This effort should take a year for full development, proper testing, and gaining of experience in modeling techniques.

Parameter studies have been initiated in an effort to determine the effects of tooth geometry and permeability on the axial and transverse magnetic forces of a magnetic bearing assembly which would support an energy storage flywheel. Further studies will be conducted to determine end effects, leakage flux, etc.

GLOSSARY

ABNCP	Airborne Command Post
ACS	Attitude Control System
A/D	An .log to Digital
AFAL	Air Force Avionics Laboratory
AFCS	Air Force Communications Service
AFML	Air Force Materials Laboratory
AFSAT	Air Force Satellite
AFSATCOM	Air Force Satellite Communications
AGC	Automatic Gain Control
AGE	Aerospace Ground Equipment
AJ	Antijam
APL	A Programming Language
ATR	Antenna Test Range
CCD	Charge-Coupled Device
CINCPAC	Commander-in-Chief, Pacific
CMOS	Complementary Metal-Oxide Semiconductor
CMS	Conversational Monitor System
COP	Communications Output Processor
CPU	Central Processor Unit
CRT	Cathode Ray Tube
CSDL	Charles S. Draper Laboratory
CVSD	Continuously Variable Slope-Delta Modulation
DCA	Defense Communications Agency
DCAS	Defense Contract Administration Services
DIMARC	Debugging Interface for the MARC
DNA	Defense Nuclear Agency
DSARC	Defense System Acquisition Review Council
DSCS	Defense Satellite Communications System
DVM	Digital Voltmeter
EIRP	Effective Irradiated Power
ERDA	Energy Research and Development Administration
ESD	Electronic Systems Division
FDMA	Frequency-Division Multiple Access
FET	Force-Element Terminal
FLTBDCST	Fleet Broadcast
FLTSAT	Fleet Satellite
FOV	Field of View
FSEC	Fairchild Space and Electronics Company

GE	General Electric Company
GSFC	Goddard Space Flight Center
GPSCS	General-Purpose Satellite Communications System
IMP	Intermodulation Products
IMPATT	Impact Ionization Avalanche Transit Time
IOC	Interim Operational Capability
IRS	Infrared Earth Sensor
ISEE-C	International Sun-Earth Explorer-C
IUS	Interim Upper Stage
JHAPL	Johns Hopkins Applied Physics Laboratory
JSOU	Jammer Source Output Units
LES	Lincoln Experimental Satellite
LESOC	Lincoln Experimental Satellite Operations Center
LLTTA	Lincoln Laboratory Transient Terminal Analyzer
LSI	Large-Scale Integration
MARC	Microprogrammed Adaptive Routing Controller
MILSATCOM	Military Satellite Communications
MSI	Medium-Scale Integration
MSO	MILSATCOM System Office
NASA	National Aeronautics and Space Administration
N/C	Numerically Controlled
NCA	National Command Authority
NCF	Nuclear Capable Forces
NELC	Naval Electronics Laboratory Center
NMM	Normal Measurement Mode
NRL	Naval Research Laboratory
PACAF	Pacific Air Force
PCSFSK	Phase-Comparison Sinusoidal Frequency-Shift Keying
PRBS	Pseudorandum Binary Sequence
RB	Re-entry Body
RF	Radio Frequency
RTG	Radioisotope Thermoelectric Generator
SADA	Solar Array Drive Assembly
SAG	Survivability Analysis Group
SAMSO	Space and Missile Systems Organization
SAOS	Solar Array Drive Orientation System
SAW	Surface Acoustic Wave

SAZ	Solar Array Sensor
SCT	Single-Channel Transponder
SHF	Super-High Frequency
S/N	Signal to Noise
SOS	Silicon on Sapphire
SSS	Strategic Satellite System
SURC	Syracuse University Research Corporation
SURVSAT	Survivable Satellite
TDM	Time-Division Multiplex
TDMA	Time-Division Multiple Access
TGG	Third-Generation Gyro
TMF	Test Management Facility
TOC	Telemetry Output Converter
TROC	Tactical Relay Operations Center
UBAC	Udylite Bright Acid Copper
UHF	Ultra-High Frequency
VCXO	Voltage-Controlled Crystal Oscillator
VSWR	Voltage Standing-Wave Ratio

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